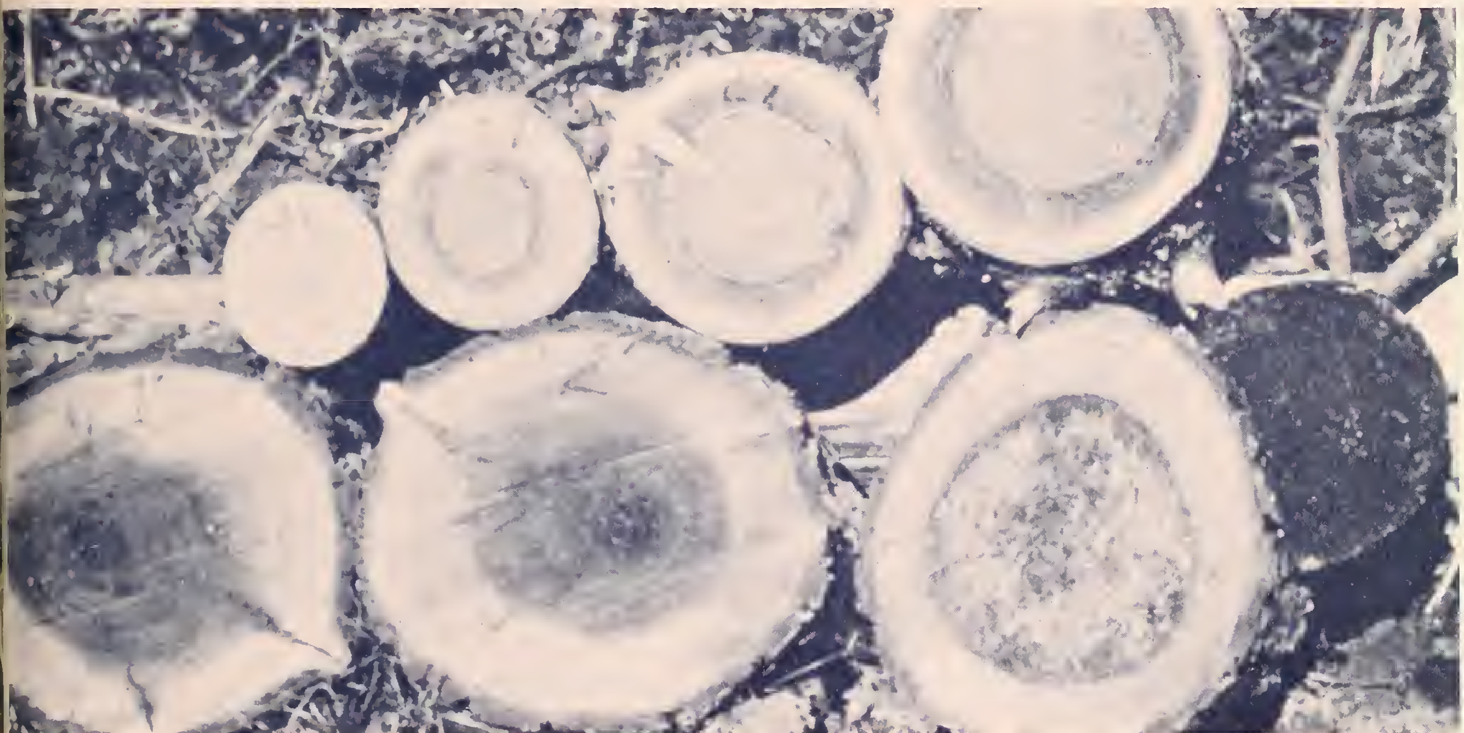
USDA FOREST SERVICE RESEARCH PAPER PNW-229
1977

Decay of Grand fir



in the Blue Mountains of Oregon and Washington

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Contents

Metric Equivalents

1 inch	= 2.54 cm
1 foot	= 0.3048 m
1 cubic foot	= 0.028 32 m^3
1 acre	= 0.4047 ha
breast height = 4.5 feet	= 137.2 cm

DECAY OF GRAND FIR IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON

Reference Abstract

Aho, Paul E.
1977. Decay of grand fir in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-229, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A total of 1,090 grand firs on 65 plots in 11 areas of the Blue Mountains of Oregon and Washington were studied for decay and other defects. Grand fir was highly defective in comparison with its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir in the study trees by one-third. Other types of defects raised the loss in board-foot volume to nearly 40 percent. Decay increased progressively with tree age and diameter, with more than 90 percent of the total cubic- or board-foot decay volume caused by white rot fungi. Defect was also related with early suppression of grand fir.

KEYWORDS: Fungi (-wood deterioration, volume (merchantable), grand fir, Indian paint fungus, Blue Mountains--Oregon, Blue Mountains--Washington.

RESEARCH SUMMARY

Research Paper PNW-229

1977

A total of 1,090 grand firs on 65 plots in 11 areas in the Blue Mountains were studied for decay and other defects. Grand fir was highly defective in comparison to its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir study trees by one-third. In addition, other types of defects and sound volume lost in cull logs resulted in nearly 40 percent unmerchantable grand fir board-foot volume. Decay varied considerably among study areas and even among plots within individual localities.

Decay increased progressively with tree age and diameter. It is not recommended that defect factors based on age or diameter classes be developed for use by cruisers, because of the wide variation in decay in individual age or diameter classes. Pathological rotation age was determined to be 125 to 150 years. Older stands will probably have defect levels which would be unacceptable to forest managers and which should be removed for better site utilization.

More than 90 percent of the total cubic- or board-foot decay

volume was caused by white rot fungi. Fourteen fungi were identified. Only four were of major significance; *Echinodontium tinctorium*, *Pholiota* sp., *Hericium abietis*, and *Fomitopsis annosa*. *Echinodontium tinctorium* alone was associated with more than 48 percent of all infections and 78 percent of the board-foot decay volume. Branches were apparently the major infection court for this fungus. *Pholiota* sp. and *H. abietis* infected trees through injuries. Trunk wounds, especially basal wounds, were most important. *Fomitopsis annosa* attacked grand firs mainly through the roots (70 percent), but also was associated with wounds including dead and broken tops.

Defect was also related with early suppression of grand fir. Although data was limited in some age classes, trees badly suppressed early in life appeared to be more defective than faster growing trees. Additional studies are needed to determine the potential future decay hazard if suppressed grand fir reproduction is used to form new forest stands.

Introduction

The associated species, grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmanii* Parry), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), and lodgepole pine (*Pinus contorta* Dougl.) generally form mixed, uneven-aged stands above the upper elevational limits of the ponderosa pine types in the Blue Mountains. These stands occur on more than a third of the commercial forest land and represent nearly half of the growing stock and board-foot volume on all ownerships.[1/] Many authors report that both grand and white fir (*A. concolor* (Gord. and Glend.) Lindl.) occur in the Blue Mountains, although Maul (1957) does not include that area in the natural range of white fir. The Blue Mountains are reported to be one of five climatic provinces of grand fir (Müller 1938). This morphologically variable complex, which will be referred to here as grand fir, has been attributed to ecological factors by Müller (1938). Grand fir, a major component of these types, has many desirable characteristics: it reproduces well, is a good competitor, is tolerant, and if not suppressed too long, grows rapidly when released. Its existing large volumes are suited for both pulp and lumber (Hubert 1955).

In the past, other species were cut in preference to grand fir; consequently, most stands of this species are mature or overmature and commonly highly defective, mainly because of decay. Productivity would be significantly increased if defective stands were harvested. Utilization and management guidelines for grand fir based on defect and decay hazard are needed for optimal use of this resource. Most decay in grand fir has been attributed to the Indian paint fungus, *Echinodontium tinctorium* Ell. and Ev. (Hubert 1955). Maloy (1967) has made an excellent, comprehensive literature review on the Indian paint fungus, and results of several significant studies have been reported since that date (Aho 1976, Aho and Hutchins 1977, Etheridge et al. 1972, Hudson 1972, Maloy 1968, Maloy and Robinson 1968). This paper will emphasize *E. tinctorium* because of the demonstrated major impact of this fungus on management and utilization of grand fir.

Methods for accurate estimation of defect in grand fir trees in the Blue Mountains have been published (Aho 1966, Aho 1974). This paper presents a more comprehensive account of decay and other defects applicable to management of grand fir in the Blue Mountains.

Methods

Sixty-six circular 1/5-acre plots were systematically selected in mature or overmature stands in 11 widely spaced localities in the Umatilla, Wallowa-Whitman, and Malheur National Forests (fig. 1). All 5-inch d.b.h. and larger trees were examined while standing. Tree species, inner bark color of grand firs, d.b.h., crown class, and condition, and the location and description of possible fungal infection courts and indicators of decay were recorded before trees were felled,

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[1/] Forest Survey data on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Figure 1.--Approximate location of grand fir study areas.

dissected, and examined for decay and other defects. Procedures for dissection and cubic- and board-foot volume measurement of trees and defect have been described previously (Aho 1966, Aho 1974).

Two ring counts were made at stump height which was usually at 1 foot above ground. The first was a total count to determine tree age, and the second was made from the pith out a radius of average growth (not the slowest or fastest areas of ring growth), to a distance of 3 inches to detect early suppression. Blocks approximately 3 inches in size were obtained from most decay columns in study trees to determine the fungi present. In the first study locality, isolations were not made from some grand firs bearing *E. tinctorium* conks because it was assumed that decay in those trees was caused by that fungus. Each evening, cultures were made by aseptically placing decayed wood chips on 2-percent malt agar slants in test tubes. Inoculated tubes were incubated at room temperatures. Fungi isolated were identified on the basis of cultural characteristics by the author and mycologists Ross W. Davidson and Frances L. Lombard, Forest Disease Laboratory, Laurel, Maryland.[2/]

Covariance analysis was used to determine whether there were significant differences between cubic-foot decay percentages in relation to tree age for trees with grand and white fir-like barks (Chapter 14, Snedecor and Cochran 1967). Formal statistical analyses were not applied to other data in this study.

Results and Discussion

Comparison of defect among species.--Six tree species were studied on the 66 plots. A total of 1,861 trees were examined for various defects. Grand fir, the most defective species comprising the commercial portion of the upper slope or mixed conifer types, made up nearly 60 percent of the sample. Table 1 summarizes the basic data for each species by pole and sawtimber size trees. Decay in sawtimber size grand fir was responsible for a loss of 14 percent of its gross merchantable cubic-foot volume and 33 percent of its board-foot volume. Defect in sawtimber size Engelmann spruce, Douglas-fir, and western larch, the other important commercial species in the mixed conifer types, is relatively small compared to grand fir. Decay caused a loss of 5.4 percent of the gross cubic volume and 11.1 percent of the gross board-foot volume of Engelmann spruce, 4.0 percent of the cubic- and 10.1 percent of the board-foot volume of Douglas-fir, and only 2.6 and 5.5 percent of the cubic- and board-foot volumes of western larch. Although only 26 sawtimber size subalpine firs were sampled, defect losses in this species were of the same magnitude as those in grand fir.

When cull rules for logs were applied and other types of defect deductions were included with decay, slightly more than 38 percent of the gross merchantable board-foot volume of grand fir was culled. Most of the additional defect losses were

[2/] Now called the Center for Mycology Research and presently located at the Forest Products Laboratory, Madison, Wisconsin.

Table 1--*Summary of basic data for associated species on 66 study plots in 11 localities in the Blue Mountains*

Species	Tree d.b.h. 5.0-10-9-inch						Tree d.b.h. 11.0-inch and greater								
	Tree basis	Average			Cubic-foot volume		Tree basis	Average			Cubic-foot volume		Board-foot volume		
		Age	D.b.h.	Height	Gross merchantable	Decay		Age	D.b.h.	Height	Gross merchantable	Decay	Gross merchantable	Decay	All defect 1/
	Number	Years	Inches	Feet	Cubic feet	Percent	Number	Years	Inches	Feet	Cubic feet	Percent	Board feet	- - Percent	- -
Grand fir	411	134	7.8	46	2,815.1	7.2	679	190	20.7	90	61,717.0	14.1	330,844	33.3	38.3
Engelmann spruce	141	119	7.5	52	1,153.2	3.3	151	154	16.9	93	10,166.5	5.4	50,345	11.1	11.8
Douglas-fir	64	134	8.3	55	541.9	1.8	160	222	21.4	97	14,644.1	4.0	77,866	10.1	10.6
Western larch	21	75	6.8	54	119.2	2.8	90	194	21.4	110	9,852.7	2.6	56,030	5.5	5.8
Subalpine fir	339	152	8.0	50	288.0	13.4	26	151	13.8	79	869.2	10.9	3,648	30.2	33.0
Lodgepole pine	63	108	7.5	55	540.6	.3	16	139	14.0	85	696.9	5.3	3,059	15.2	15.2

1/ In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

caused by shake and frost cracks which were associated with wetwood, usually in the butt log. Wetwood is a condition of unknown origin in which the heartwood is excessively wet. With the exception of subalpine fir, the other species seldom had wetwood or its associated defects, shake, or frost cracks. Thus, decay caused nearly all the defect in Engelmann spruce, Douglas-fir, western larch, and lodgepole pine.

Defect percentages shown in table 1 may be somewhat higher than actual average board-foot defect in these species in the Blue Mountains. Most plots were in sale areas, which are generally located in the older, more defective stands.

Distribution of decay in grand fir by study location.--There was wide variation in decay losses in sawtimber and pole size grand fir from study locality to locality (table 2). Cubic-foot decay of trees greater than 11-inch d.b.h. ranged from less than 1 percent at Deardorff Ridge to 32 percent at Mount Nebo. In 6 of the 11 study areas , board-foot decay in sawtimber trees exceeded 40 percent of total gross merchantable volume. Decay in pole size trees (5.0-10.9 inch d.b.h.) also varied from locality to locality, but not to the extent it did in sawtimber trees. Cubic decay varied from less than 1 percent at Deardorff Ridge to nearly 14 percent at Texas Bar. Decay variation in both pole and sawtimber size trees could not be explained solely on the basis of age. For example, in the Round Mountain locality, sawtimber averaged 157 years and decay was 21.6 percent of gross board-foot volume. In the Summit Spring area, average age was 153 years but decay was 55.9 percent of the gross board-foot volume.

Decay not only varied among study localities but also from plot to plot in individual localities. For instance, on the 13 plots taken in the Round Mountain study area, board-foot decay in sawtimber trees ranged from less than 1 percent to nearly 50 percent, even though many of the plots were only a few chains apart. Again, the variation could not be explained by average age of trees on the plots.

Decay variation between grand firs with different bark characteristics.--According to Müller (1938), grand firs growing on exposed, dry sites will exhibit bark (and needle) characteristics similar to white fir. The inner bark of grand fir is usually reddish to reddish purple while that of white fir is greyish white, resembling that of Douglas-fir. Trees were separated on the basis of inner bark color. There were 644 trees with white fir-like inner bark and 446 with grand fir-like bark. Covariance analysis was used to determine whether or not there were differences in decay in relation to tree age for the two groups. Significant differences (at the 1-percent level) were found in the slopes of the regression surfaces and elevations (means) of the regression lines for the two groups of trees. Cubic-foot decay percents were lower for the grand fir-like trees up to 150 years; but after that age, they increased much more rapidly than for the white fir-like group.

Infection and subsequent decay development may be limited by environmental conditions in dry, exposed sites where trees with white fir-like bark are found. Weir and Hubert (1919) found that total number of trees infected by *E. tinctorium*, live trees with sporophores, and total number of live sporophores were reduced on cutover areas. They suggested that increased light and reduced moisture conditions affect germination and penetration of basidiospores of the Indian paint fungus. Maloy (1963) found that shade was important for survival of *E. tinctorium* sporophores on felled grand firs.

Table 2--*Summary of basic data for grand fir by study localities*

Study locality and Ranger District	Tree d.b.h. 5.0- to 10.9-inch							Tree d.b.h. 11.0-inch and greater									
	Basis		Average			Cubic-foot volume		Basis		Average			Cubic-foot volume		Board-foot volume		
	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Gross merchantable	Decay	All defect[1/]
	- - Number - -		Years	Inches	Feet	Cubic feet	Percent	- - Number - -		Years	Inches	Feet	Cubic feet	Percent	Board feet	- - Percent - -	
Round Mountain, Pendleton	6	12	102	10.0	66	179.0	8.9	13	124	157	23.3	98	14,152.6	9.0	78,607	21.6	27.5
Mount Nebo, Joseph	7	33	130	7.3	40	144.9	12.5	9	57	219	19.9	88	4,782.3	32.0	26,628	58.9	61.4
Abel's Ridge, Pomercy	5	49	124	8.2	55	473.0	4.0	5	59	194	21.0	95	5,918.1	15.8	32,405	39.4	43.4
Swamp Creek #2, Walla Walla	5	14	173	8.0	45	120.2	4.3	6	86	178	22.5	108	11,321.8	7.5	64,357	18.6	21.7
Texas Bar, Ukiah	6	59	159	7.9	42	334.0	13.8	6	74	211	20.4	89	6,265.7	18.0	32,640	45.0	61.3
Summit Spring, Bear Sleds	6	103	120	7.9	53	828.7	8.5	6	68	153	18.1	89	5,093.9	23.0	26,656	55.9	62.2
Wolf Creek, Baker	7	34	162	7.6	39	168.3	4.0	8	66	209	18.8	82	4,658.6	8.2	23,526	21.1	23.6
Trout Farm, Prairie City	3	20	206	8.0	34	113.0	12.1	3	35	259	19.9	85	2,620.7	22.1	12,788	56.6	59.2
Deardorff Ridge, Prairie City	3	39	77	7.7	47	264.2	.2	3	34	103	18.9	85	2,353.0	.8	11,576	3.6	3.7
Wiley Creek, Long Creek	3	33	131	6.8	30	121.6	3.4	3	29	200	18.0	66	1,478.8	22.4	6,572	63.7	63.7
Onion Spring, Prairie City	3	15	179	7.6	34	68.2	2.4	3	47	255	20.2	74	3,071.5	16.5	15,089	41.7	42.9
Total or average	54	411	134	7.8	46	2,815.1	7.1	65	679	190	20.7	90	61,717.0	14.1	330,844	33.3	38.3

1/ In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

Decay and total defect in relation to age.--Decay generally increases in incidence and severity with increasing tree or stand age (Wagener and Davidson 1954). Grand firs in this study were sorted into 50-year age classes and percent decay and defect[3] determined for each class (fig. 2). Both decay and defect increase with age. Grand fir was reported to be subject to serious decay losses at an early age in Idaho (Hubert 1955, Maloy and Gross 1963) and in the Blue Mountains because of the prevalence of decay in mature and over-mature trees (Boyce 1930). This study, however, indicates that decay and other defects are not a serious problem in young trees nor are they likely to be in future rotations of grand fir under intensive management in the Blue Mountains. Board-foot defect in trees younger than 100 years old was less than 3 percent of total gross volume and slightly more than 13 percent in trees from 100 to 149 years old. Rotation ages over 125 years will probably be uncommon in managed stands of the future. Even under partial cut management, grand fir stands can be kept relatively free of defect for many years provided that logging wounds are held to a minimum on residual trees and wounded and conked trees are removed in intermediate cuts.

Total board-foot defect loss in the 150- to 199-year age class was 32 percent, approximately 47 percent in the 200-249-year age class, and nearly 70 percent for all trees over 250 years old. Removal and utilization of grand fir stands over 250 years old is a serious forest management

[3] Defect in board foot measure includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

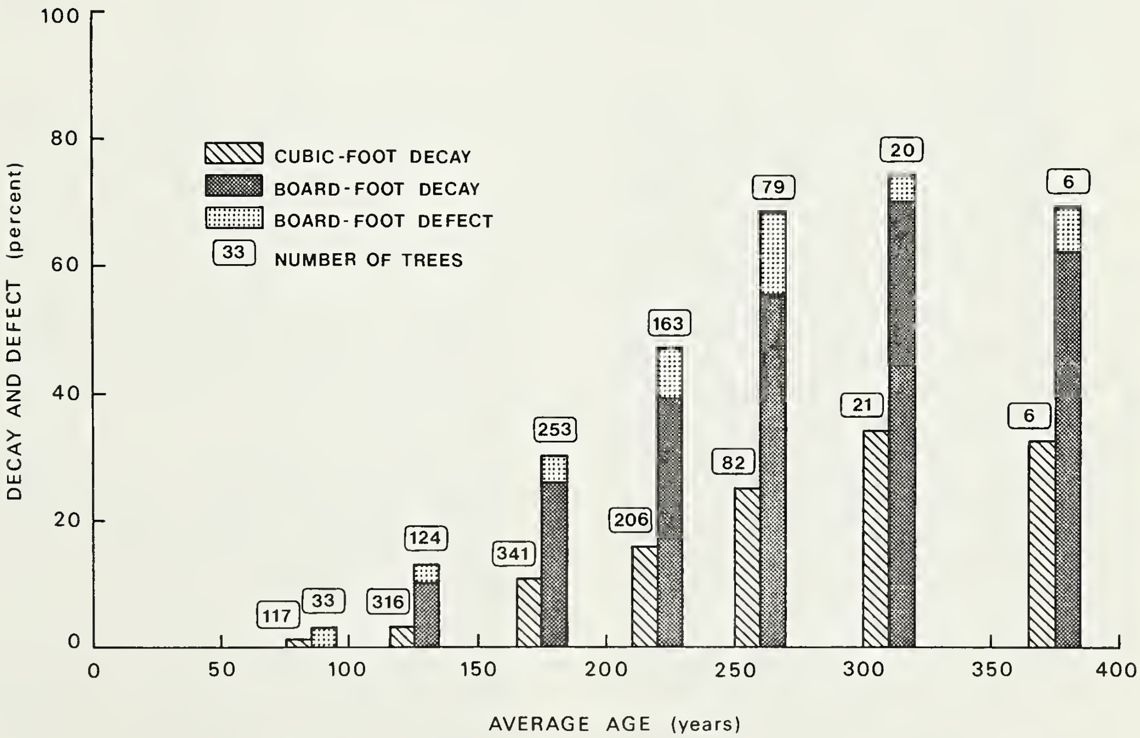

Figure 2.--Percent of cubic- and board-foot volumes decayed and total board-foot defect in grand fir by 50-year age classes.

problem in the Blue Mountains. Logging costs are greater in defective than in sound stands; and since both quantity and quality of logs are affected, logging costs may not be recovered.

Distribution of trees with various amounts of decay within age classes.--Defect factors based on tree or stand age are used in presale or inventory cruises (Wagener and Davidson 1954). Since decay is usually correlated with age, this may be a realistic and relatively simple method to use. Grand firs in each 50-year age class were grouped by the amount of decay (percent of their total board-foot volume) they contained (table 3).

for individual trees or stands. Estimation of defect or decisions on which trees to harvest should not be based on age alone, but on a combination of factors as described by Aho (1974).

Decay in relation to diameter.--Since diameter is a function of age, the incidence and severity of decay should also increase with diameter. It may be more practical to develop defect factors for diameter classes than for age, because diameter (d.b.h.) is easy to measure. This has been done successfully for some tree species (Wagener and Davidson 1954). When all grand firs in this study were sorted by d.b.h., decay and defect increased with diameter (table 4). Decay and

Table 3--*Distribution of grand firs with various amounts of board-foot decay by 50-year age classes*

Age class	Tree basis	Trees by board-foot decay class						Board-foot decay volume
		No decay	0.1 to 10	11 to 25	26-50	51-75	76-100	
Years	Number	Percent						
50-99	33	97	3	0	0	0	0	1/
100-149	124	70	9	4	2	6	9	10.2
150-199	253	40	10	9	13	11	17	25.9
200-249	163	30	7	10	8	17	28	38.9
250-299	79	13	8	5	14	23	37	55.7
300-349	20	15	5	15	10	5	50	69.6
350-399	6	0	17	17	0	33	33	61.8
450-499	1	0	0	0	0	0	100	96.9
Total or average	679	41	9	8	9	12	21	33.3

1/ Less than 0.5-percent decay.

There was a progressive decrease in trees without measurable decay from 97 percent in the 50- to 99-year age class to none in the 350- to 399-year age class. There was a general increase in percentage of trees in each defect class with increasing age classes. There is considerable variation in decay in trees in the same age class. Trees in the 100- to 149-year class had an average of 10.2 percent board-foot decay, but 70 percent of the trees were completely free of decay; while 15 percent had less than, and 15 percent more than, 50 percent of their volumes decayed. Defect factors for broad age classes of grand fir are not reliable

defect, however, were high in all diameter classes over 11-inch d.b.h. Each diameter class consisted of a wide range of ages because of suppression. When trees in each diameter class were sorted by age, there was a progressive increase in decay with increasing age. Thus, age more accurately reflects extent of decay than does diameter.

Distribution of trees with various amounts of decay within diameter classes.--The distribution of trees with various amounts of board-foot decay varied within each diameter class (table 5) just as it did with age. Of the 363 trees in the 11.0- to 18.9-inch

Table 4--*Decay and defect related to diameter of grand fir*

Diameter class	Tree basis	Average age	Decay volume		All board-foot defect
			Cubic feet	Board feet	
Inches	Number	Years	Percent		
5.0-10.9	411	135	7.1	1/	1/
11.0-18.9	363	174	10.8	29.1	33.7
19.0-26.9	225	201	12.5	30.3	37.1
27.0-34.9	75	221	16.3	33.6	41.4
35.0-42.9	16	251	23.9	54.2	65.9
Total or average	1,090	169	13.8	33.3	38.3

1/ Board foot volume is not calculated for pole-size trees.

Table 5--*Distribution of grand firs with various amounts of board-foot decay by diameter classes*

Diameter class	Tree basis	Trees by board-foot decay class						Board-foot decay volume
		None	0.1 to 10	11 to 25	26 to 50	51 to 75	76 to 100	
Inches	Number	Percent						
11.0-18.9	363	47	8	7	6	9	23	29.1
19.0-26.9	225	36	10	10	13	14	17	30.3
27.0-34.9	75	36	8	5	16	15	20	33.6
35.0-42.9	16	0	13	6	6	50	25	54.2

diameter class, 47 percent were free of measurable decay, but nearly a third had more than 50 percent of their board-foot volume decayed. Although it may be practical or even justified for timber cruisers to use average defect factors by diameter classes for some species, it would be impractical to do so for grand fir, since inaccurate net volumes would result.

Decay in relation to early suppression.--Grand fir is a tolerant species and is often subjected to long periods of suppression and slow growth. There is conflicting evidence in the literature that decay is related to suppression in various tree species (Boyce 1961). To determine the relation of decay to suppression in grand fir, trees were sorted into three arbitrary early suppression classes based on a 3-inch ring count from the pith along a radius of average growth at stump height. Cubic-foot decay percentages for each suppression class were compared by 50-year age classes. Fast growing trees (26-75 rings) in each age class are considerably larger in d.b.h. and height than the moderately fast growing trees (76-125 rings) which are larger than the slowest growing (126+ rings) or most suppressed trees (table 6). Cubic decay as a proportion of total volume of each suppression or growth class ranged from 9.7 percent in the fast growing, to 17.7 percent in the moderately fast growing, to 24.7 percent in the slow growing trees.

Although there were only 10 trees between 100-149 years of age in the slowest growing class (126+ rings), the data suggest that decay is more serious in this class than in the fast and moderately slow growing

Table 6--*Decay in relation to early suppression of grand fir*

Basic data for suppression classes	Age class (years)									Total or average
	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-499	450-499	
26-75 rings										
Tree basis (Number)	100	121	159	27	5	0.0	0.0	0.0	0.0	412
Average 3-inch ring count (Number)	48	60	52	64	63	0.0	0.0	0.0	0.0	54
Average age (Years)	77	123	173	214	278	0.0	0.0	0.0	0.0	139
Average d.b.h. (Inches)	10.2	16.3	22.0	24.8	35.1	0.0	0.0	0.0	0.0	17.8
Average height (Feet)	63	85	106	104	106	0.0	0.0	0.0	0.0	89
Average cubic-foot volume (ft^3)	20.0	64.3	130.9	151.7	232.2	0.0	0.0	0.0	0.0	87.0
Cubic-foot decay (Percent)	1/	4.1	10.8	15.6	24.0	0.0	0.0	0.0	0.0	9.7
76-125 rings										
Tree basis (Number)	17	185	137	109	46	14	5	0.0	0.0	513
Average 3-inch ring count (Number)	82	94	98	99	106	111	109	0.0	0.0	98
Average age (Years)	95	123	173	217	271	318	369	0.0	0.0	176
Average d.b.h. (Inches)	6.5	8.2	13.2	18.5	26.2	21.7	30.0	0.0	0.0	13.9
Average height (Feet)	42	48	67	80	101	91	105	0.0	0.0	67
Average cubic-foot volume (ft^3)	4.2	11.3	32.0	71.2	151.2	92.0	203.7	0.0	0.0	45.9
Cubic-foot decay (Percent)	1.9	2.7	10.2	16.2	25.0	31.9	26.3	0.0	0.0	17.7
126+ rings										
Tree basis (Number)	0.0	10	45	69	31	7	1	0.0	1	164
Average 3-inch ring count (Number)	0.0	130	143	152	150	180	162	0.0	163	150
Average age (Years)	0.0	141	177	223	275	334	390	0.0	472	222
Average d.b.h. (Inches)	0.0	6.4	8.2	11.8	17.6	17.6	33.8	0.0	34.5	12.1
Average height (Feet)	0.0	35	42	59	77	73	2/	0.0	110	57
Average cubic-foot volume (ft^3)	0.0	2.1	7.9	27.2	64.0	57.4	265.6	0.0	195.9	31.1
Cubic-foot decay (Percent)	0.0	10.0	8.7	15.6	27.3	40.7	54.7	0.0	42.2	24.7

1/ Less than 0.1-percent decay.

2/ No height because the tree had a broken top.

classes, which are about equally defective. From 150-299 years, decay in the three suppression or growth classes is similar. Although the sample was small, slow growing trees were more defective than the moderately slow growing trees in age classes over 300 years.

Meinecke (1916) reported that up to 150 years of age, decay is most severe in suppressed or slow growing white firs in southwestern Oregon. After 150 years, all trees are equally defective, regardless of suppression or growth rate. Boyce (1961) concluded that "lack of vigor expressed by suppression tends to increase decay in the earlier years in certain species, but as trees grow older this influence disappears, and fast-grown trees may be as much decayed as or even more than slow-grown trees."

These findings, along with those of Etheridge et al. (1972) and Aho and Hutchins (1977) on the mode of infection by the Indian paint fungus, suggest that studies should be undertaken to determine whether or not suppressed grand fir regeneration is infected by decay fungi and subject to serious decay after release and before rotation age.

Fungi associated with decay.--Fungi associated with nearly 72 percent of all decay columns in grand fir were identified (table 7). These decay columns accounted for nearly 92 percent of the total board-foot and cubic-foot decay volumes. Although the fungi causing 28.3 percent of the decay columns were unidentified, their impact in terms of volume losses was small.

Although grand fir heartwood was attacked by many fungi, only 14 were identified. Most of the decay was associated with white trunk rot fungi, which were respondible for 62 percent of the total number of infections and nearly 84 percent of the total board-foot decay volume (table 7). Of the white root and butt rots, only *Fomitopsis annosa* (*Fomes annosus*) (Fr.) Karst. caused significant numbers of infections, but associated decay volumes were relatively small.

Table 7--*Fungi associated with decay of grand fir*

Fungus	Infections		Average decay volume[1]		Percent total decay volume[1]	
	Number	Percent	Cubic feet	Board feet	Cubic feet	Board feet
White trunk rots:						
Echinodontium tinctorium Ell. & Ev.	270	45.5	24.1	376	72.9	70.9
Pholiota sp.	57	9.6	10.6	167	6.8	7.9
Hericium abietis (Weir ex Hubert) K. Harrison	35	5.9	9.2	148	3.6	4.2
Phellinus (*Fomes*) *pini* (Thore ex Fr.) Pilát	3	.5	22.6	248	.8	.7
Amylostereum (*Stereum*) *chailletii* (Pers. ex Fr.) Boid.	2	.3	1.3	24	3/	3/
Hirschioporus (*Polyporus*) *abietinus* (Dicks. ex Fr.) Douk	1	.2	.3	8	3/	3/
Stereum sanguinolentum Alb. & Schw. ex Fr.	1	.2	.9	8	3/	3/
White root and butt rots:						
Fomitopsis (*Fomes*) *annosa* (Fr.) Karst.	30	5.0	2.5	58	.9	.7
Polyporus tomentosus Fr. var. *circinatus* (Fr.) Satory & Maire	2	.3	.5	15	3/	3/
Armillariella mellea (Fr.) Karst.	3	.5	5.0	132	.2	.4
Corticium galactinum (Fr.) Burt	1	.2	.1	4/ 0	3/	4/ 0
Brown trunk rots:						
Coniophora puteana (Schum. ex Fr.) Karst.	2	.3	1.8	36	3/	3/
Trechispora raduloides (Karst.) Rogers	1	.2	30.7	388	.3	.4
Fomitopsis (*Fomes*) *pinicola* (Swartz ex Fr.) Karst.	1	.2	.1	3	3/	3/
Mixed 2/:						
E. tinctorium - *Pholiota* sp.	12	2.0	38.9	515	5.2	5.6
E. tinctorium - *H. abietis*	3	.5	25.4	502	.9	.9
Pholiota sp. - *H. abietis*	2	.3	6.8	132	.2	.1
Unidentified	168	28.3	4.4	74	8.2	8.2
Total or average	594	100.0	15.0	242	100.0	100.0

1/ Infections in pole and sawtimber size trees are included under cubic-foot measurement, but only infections in trees larger than 11.0-inch d.b.h. are included under board-foot measurement.

2/ Fungi associated in mixed infections as determined by cultural techniques.

3/ Less than 0.05 percent of the total cubic- or board-foot decay volume.

4/ No board-foot decay volume because the infection was in a pole-size tree.

There were no identified brown root and butt rots and only four brown trunk rots with insignificant amounts of decay.

Of the 14 identified fungi, only 4 were important in number of infections and decay volumes. These four fungi, *E. tinctorium*, *Pholiota* sp., *Hericium abietis* (Weir ex Hubert) K. Harrison, and *F. annosa*, were commonly isolated from grand firs in Idaho (Maloy 1968, Hudson 1972) and from white fir in southwestern Oregon (Aho 1976). The most important was the Indian paint fungus, *E. tinctorium*, which causes a rust red stringy rot often extending from the roots to above the merchantable top of infected trees. Alone, this fungus caused 45.5 percent of all infections and nearly 71 percent of the total board-foot decay volume. Including mixed infections with *Pholiota* sp., or the fir hydnum, *H. abietis*, the Indian paint fungus was associated with over 48 percent of all decay columns and over 78 percent of the board-foot decay volume. Mixed attacks of *E. tinctorium* and *Pholiota* sp. or *H. abietis* caused more volume loss than single infections by these fungi. Mixed infections by two or more hymenomycete fungi apparently are common in grand and white firs (Hudson 1972, Miller and Partridge 1973, Aho 1976). Hudson (1972) found *H. abietis* associated with 10 of 35 grand firs infected with the Indian paint fungus in a study in Idaho; and Aho (1976) commonly isolated both *H. abietis* and *Pholiota* sp. from *E. tinctorium* decay in white fir in Oregon. Aho (1976) also presented evidence of multiple infections in white firs by *E. tinctorium*. Multiple infections by individual or two or more decay fungi may explain how extensive (roots to tree top) decay columns develop so rapidly in relatively young grand and white firs.

Although *Phellinus* (*Fomes*) *pini* (Thore ex Fr.) Pilát has been reported

to be an important heart rot fungus of balsam firs in other regions, it caused only three infections in this study; but the resultant average decay loss was third highest of all fungi (table 7). *Stereum sanguinolentum* Alb. & Schw. ex Fr. also causes major losses in balsam firs elsewhere and was frequently isolated from grand firs in Idaho (Maloy 1968, Hudson 1972), but it caused only one identified infection in this study.

Odontia bicolor (Fr.) Bres. was isolated from decays in grand fir in Idaho (Maloy 1968, Hudson 1972), but was not isolated in this study. *Phellinus* (*Poria*) *weirii* (Murr.) Gilb. and *P.* (*Fomes*) *nigrolimitatus* (Rom.) Bourd, and Galz. were two of the most common fungi associated with root rots in grand fir in Idaho (Miller and Partridge 1973). Extensive *P. weirii* foci were seen adjacent to our plots, but neither *P. weirii* nor *P. nigrolimitatus* were isolated from decay in study trees.

Impact of E. tinctorium in grand fir.--The impact of the Indian paint fungus on management and utilization of grand fir in the Blue Mountains cannot be over emphasized. This fungus caused infections in 26 percent of the 1,090 grand fir study trees (table 8). Only four trees less than 100 years of age were decayed by this fungus. This is contrary to Hubert's (1955) report that in Idaho the Indian paint fungus attacks and produces numerous conks on young grand firs. This fungus, however, was not found or only occasionally isolated from trees under 100 years of age by other researchers in Idaho (Maloy 1968, Hudson 1972). In this study, the percentage of trees infected by *E. tinctorium* increased with age from 3 percent in the 50- to 99-year age class to 50 percent or greater in age classes from 250 to 299 years and older (table 8).

Seventy-seven percent of all grand firs infected by the Indian paint fungus had conks. Conkless *E. tinctorium* infected trees were present in every age class. Many infected trees without conks had decay columns which hadn't developed sufficiently to sporulate, or conks had apparently fallen off some trees with very old infections. These types of trees are misread by timber cruisers, causing substantial errors in their net volume estimates.

Total cubic decay volume and the percentage of decay caused by *E. tinctorium* are shown by 50-year age classes in table 8. Decay caused by the Indian paint fungus ranged from a third of the total in trees under 100 to over 73 percent in older age classes.

Table 8--Echinodontium tinctorium *infections and decay volume in grand fir by age classes*

Age class	Tree basis	*Echinodontium tinctorium* infections				Cubic-foot decay volume	
		Trees	Proportion of trees in age class	With conks	Proportion of *E. tinctorium* infections with conks	Total	Proportion of total caused by *E. tinctorium*
	- - Number - -		Percent	Number	Percent	Cubic feet	Percent
50-99	117	4	3.4	1	25.0	12.6	33.3
100-149	316	32	10.1	23	71.9	377.0	76.3
150-199	341	111	32.6	89	80.2	2,727.4	82.1
200-249	206	76	36.9	59	77.6	2,186.4	73.6
250-299	82	46	56.1	38	82.6	2,557.9	76.7
300-349	21	12	57.1	7	58.3	574.5	86.5
350-399	6	3	50.0	2	66.7	413.6	78.3
450-499	1	1	100.0	1	100.0	82.7	100.0
Total or average	1,090	285	26.1	220	77.2	8,932.1	78.3

From these data there can be no doubt of the importance of *E. tinctorium* at least in mature and overmature stands of grand fir in the Blue Mountains.

Infection courts for fungi.--The apparent infection courts for fungi attacking grand fir are listed in table 9. Nearly 85 percent of all *E. tinctorium* infections apparently occurred through branches. Some young infections were traced to an individual dead branch or to a whorl of branches. If other injuries were not present, old infections by the Indian paint fungus were assumed to have originated at the branch stub to which the oldest conk was attached. The decay column at that point was usually most advanced in deterioration and size. On this basis many investigators have reported that dead branches and stubs are the primary infection court for *E. tinctorium* (Weir and Hubert 1918, Kimmey 1965, Thomas 1958). Since this study was completed, Etheridge et al. (1972) have determined that the Indian paint fungus infects western hemlock through shade suppressed twigs less than 2 mm in size on living branches. The fungus enters tissues of the pith area of the living main branch through secondary branch traces and remains semiquiescent until conditions arise which promote further growth. Etheridge et al. (1972) speculated that moisture and aeration changes within the branch brought on by branch death or injury promote further growth of the fungus and entrance into the main bole. Preliminary evidence suggests that the Indian paint fungus may infect grand fir in the same manner (Aho and Hutchins 1974).

Nearly 14 percent of the *E. tinctorium* infections were traced to a wide variety of other entrance courts, mainly injuries (table 9). Others have reported that injuries are also infection courts for the Indian paint fungus (Meinecke 1916, Hubert 1955, Boyce 1961). It could be speculated that the injuries may not be the infection site but may promote growth of semiquiescent infections of *E. tinctorium* which are already present (Etheridge et al., 1972) in the tree. Other fungi may invade the injuries resulting in decay columns caused by two or more hymenomycetes. Additional research is needed to resolve this important step in the infection process by *E. tinctorium.*

Pholiota sp. was responsible for the second highest number of infections (table 9). Most infections (66.7%) by *Pholiota* sp. occurred through basal wounds.

The fir hydnum, *H. abietis* caused 35 infections, mainly entering through wounds (table 9). Hudson (1972) did not consider this fungus to be a primary invader of grand fir heartwood. He found it mainly associated with *E. tinctorium* decay columns in older trees and was unable to locate its entry courts. Maloy (1968) isolated *H. abietis* from wounds in young grand firs. Aho (1976) found the fir hydnum as a primary invader of white fir (its infection courts were much the same as in table 9) and also as a common associate of *E. tinctorium* and other decay columns.

Fomitopsis annosa was responsible for 30 infections, mainly entering trees through roots (table 9). Root rot pockets caused by *F. annosa* occurred on some plots, however, infected trees were not killed. Although commonly a root and butt rot, this fungus also infected trees through dead and broken tops.

Other identified fungi caused relatively few infections in study trees. Unidentified fungi were associated with every type of infection court, but the most important were basal and trunk injuries.

The relative importance of apparent infection courts in grand fir in terms of number of infections and associated decay volumes is shown in table 10.

Table 9--*Apparent infection courts for fungi attacking grand fir*

Fungus	Apparent infection court											
	Branches	Roots	Basal injuries	Trunk injuries	Frost cracks	Forks	Crooks	Crooks and dead vertical branches	Dead vertical branches	Broken tops	Dead tops	Unknown	Total
	Percent												Number
White trunk rots:													
Echinodontium tinctorium	84.8	0.0	4.4	3.7	2.2	0.0	0.7	0.4	0.4	0.7	1.2	1.5	270
Pholiota sp.	0.0	5.2	64.8	8.8	8.8	1.8	1.8	1.8	3.5	3.5	0.0	0.0	57
Hericium abietis	11.3	5.6	25.7	17.2	22.9	2.9	8.6	2.9	0.0	0.0	2.9	0.0	35
Phellinus pini	66.7	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
Amylostereum chailletii	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	2
Hirschioporus abietinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	1
Stereum sanguinolentum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	1
White root and butt rots:													
Fomitopsis annosa	0.0	70.0	6.7	3.3	10.0	0.0	0.0	0.0	0.0	6.7	3.3	0.0	30
Polyporus tomentosus var. *circinatus*	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
Armillariella mellea	0.0	66.7	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3
Corticium galactinum	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
Brown trunk rots:													
Coniophora puteana	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	2
Trechispora raduloides	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
Fomitopsis pinicola	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
Unidentified	1.2	11.3	39.3	17.2	8.3	0.6	3.0	0.6	3.6	9.5	5.4	0.0	168
Total infections[1/]	41.1	8.7	22.7	9.0	6.2	0.5	1.9	0.7	1.6	4.0	2.9	0.7	577

1/ Does not include entrance courts for 17 mixed fungal infections.

Table 10--*Relative importance of apparent infection courts for fungi attacking grand fir*

Infection court	Total	Infected	Proportion of total infections[1/]	Amount of decay per infection court		Proportion of total decay	
				Cubic feet	Board feet	Cubic feet	Board feet
	Number	Percent	Percent	- - Average - -		- - Percent - -	
Branches	250	--	42.1	24.1	376	67.5	67.5
Roots	50	--	8.4	1.0	31	.6	.8
Basal injuries	180	73.8	22.4	6.6	103	13.3	13.7
Trunk injuries	145	36.6	8.9	4.3	75	7.0	6.6
Frost cracks	615	5.9	6.1	.5	8	3.4	4.0
Forks	27	14.8	.7	3.2	47	1.0	1.0
Crooks	72	15.3	1.8	1.1	17	.9	.8
Crooks and dead vertical branches	15	26.7	.7	3.0	40	.5	.4
Dead vertical branches	46	19.6	1.4	1.1	22	.6	.8
Broken tops	54	42.6	3.9	1.5	22	.9	.6
Dead tops	29	58.6	2.9	3.4	52	1.1	.7
Unknown	4	100.0	.7	70.7	849	3.2	3.1

[1/] Includes apparent infection courts for 17 mixed fungal infections.

More than 42 percent of all infections apparently occurred through branches. These infections accounted for nearly 68 percent of the total cubic- and board-foot decay volumes. This probably is a reflection of the importance of *E. tinctorium* in causing decay in mature and overmature grand firs.

Basal injuries, especially old fire scars, were the second most important infection courts. Nearly 74 percent of 180 basal wounds were infected, and they accounted for more than 22 percent of all infections and nearly 14 percent of the board-foot decay volume in study trees. Trunk wounds were next in importance. More than 36 percent of 145 trunk injuries were infected resulting in a volume loss of 75 board-feet per infection. In the future, basal and trunk wounds will probably be the most important infection courts in young, intensively managed grand fir stands. Wound-invading fungi, such as *Pholiota* sp. or *H. abietis* may replace *E. tinctorium* as the most important heart rot fungus in grand fir.

Frost cracks have not been considered to be important infection courts for decay fungi in grand or white firs (Maloy and Gross 1963, Hudson 1972, Aho 1976). In this study, less than 6 percent of 615 frost cracks were infected and associated decay losses were small (table 10). Frost cracks were especially prevalent at the base of trees infected by *E. tinctorium*.

Nearly 59 and 43 percent of dead and broken tops, respectively, were infected by decay fungi. Aho (1976) found these injuries, especially dead tops, to be excellent infection courts in white fir. A high incidence of decay was found associated with dead tops in balsam fir (Stillwell 1956) and in red and white firs in California (Kimmey 1950). Wickman and Scharpf (1972), found little decay associated with white fir tops killed by the Douglas-fir tussock moth in California.

Crooks and dead vertical branches were infrequently infected; and when they were, associated decay volumes were relatively small (table 10). When crooks and dead vertical branches occurred together, both number of infections and average decay volumes were considerably higher than for either infection court alone.

Conclusions

Grand fir is the most defective of the major commercial species comprising the associated species or mixed conifer types in the Blue Mountains. Nearly 40 percent of the merchantable board-foot volume of grand fir study trees was culled. Grand fir defect loss (percentage of total volume) was more than three times greater than that in Douglas-fir, western larch, or Engelmann spruce. It was not unusual for defect in some grand fir stands to range from 65 to as much as 85 percent. Removal of the highly defective trees is essential so these sites can be put back into maximum production.

Decay in grand fir was found to increase with increasing tree age and diameter. There was so much variation in decay within trees in various age and diameter classes that broad defect factors based on these variables alone are not recommended.

Pathological rotation age in clearcut management, in most localities, should not exceed 150 years otherwise decay losses may be unacceptable. Rotation age based on other considerations will probably seldom exceed 125 years in grand fir. Even in multiple (selection) cut management, it should be possible to hold defect in stands to low levels provided that leave trees are not wounded and that conked and injured trees are removed in intermediate cuts.

It is necessary to inject a word of warning here. Recent studies (in western hemlock and grand fir) have indicated that suppressed grand fir regeneration may be infected with dormant infections by *E. tinctorium* and other decay fungi. If suppressed trees 50 to 75 years old with many dormant infections are released to form new stands, these trees may be very defective at harvest age.

It is not known to what extent trees are infected or whether these infections will cause decay after the regeneration is released. The conditions causing continued growth of the semiquiescent infections are also not known. Death of infected branches or other injuries have been suggested as triggering continued growth in western hemlock (Etheridge et al. 1972). Studies are underway to determine the extent of this potential future decay problem.

Although 14 fungi were identified as causing decay in grand fir in this study, only four caused more than three infections or significant cull losses. They were *E. tinctorium*, *Pholiota* sp., *H. abietis*, and *F. annosa*. Of these, *E. tinctorium*, was of major importance. The Indian paint fungus was associated with more than 48 percent of all infections which accounted for almost 80 percent of the total board-foot decay volume in grand fir. Nearly 85 percent of the infections caused by this fungus apparently originated through branches.

Pholiota sp. and *H. abietis* attacked trees through injuries; the most important being basal and trunk wounds. Although *E. tinctorium* is without a doubt the major decay fungus in old-growth grand fir stands, *Pholiota* sp. or *H. abietis* may become more important in young, intensively managed stands. Wounding of residual trees during thinning and selection harvest operations must be held to a minimum. Of course, the Indian paint fungus may be a significant factor in stands formed from advanced reproduction.

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A total of 1,090 grand firs on 65 plots in 11 areas of the Blue Mountains of Oregon and Washington were studied for decay and other defects. Grand fir was highly defective in comparison with its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir in the study trees by one-third. Other types of defects raised the loss in board-foot volume to nearly 40 percent. Decay increased progressively with tree age and diameter, with more than 90 percent of the total cubic- or board-foot decay volume caused by white rot fungi. Defect was also related with early suppression of grand fir.

KEYWORDS: Fungi (-wood deterioration, volume (merchantable), grand fir, Indian paint fungus, Blue Mountains--Oregon, Blue Mountains--Washington.

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1977. Decay of grand fir in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-229, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A total of 1,090 grand firs on 65 plots in 11 areas of the Blue Mountains of Oregon and Washington were studied for decay and other defects. Grand fir was highly defective in comparison with its associated species in the mixed conifer types. Decay reduced the net board-foot volume of grand fir in the study trees by one-third. Other types of defects raised the loss in board-foot volume to nearly 40 percent. Decay increased progressively with tree age and diameter, with more than 90 percent of the total cubic- or board-foot decay volume caused by white rot fungi. Defect was also related with early suppression of grand fir.

KEYWORDS: Fungi (-wood deterioration, volume (merchantable), grand fir, Indian paint fungus, Blue Mountains--Oregon, Blue Mountains--Washington.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.